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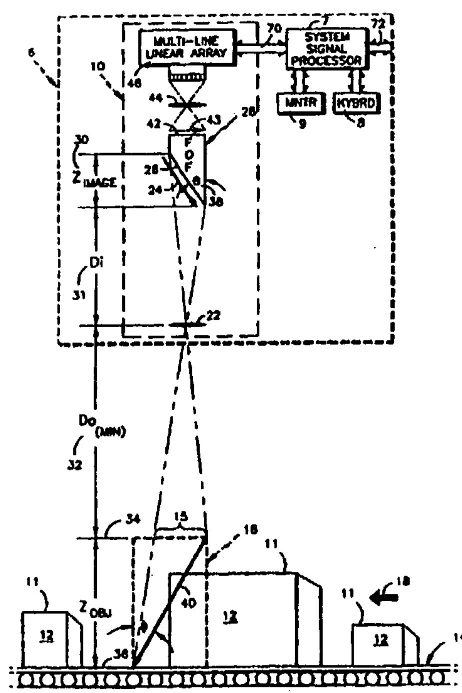
(54) Title: MULTI-FOCAL VISION SYSTEM

(57) Abstract

A machine vision system images bar code labels moving through a horizontal plane at variable object distances within the system's object depth of field Z_{obj} with a plurality of sequential line images, each with different object lengths which gradate Z_{obj} into plural focused object planes, and the object plane within which the bar code label lies provides a focused optical image of the bar code to a multilinear photodetector which transduces the focused optical image into a corresponding electrical siganal for further processing.



INTERNATIONAL SEARCH REPORT

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Description

Multi-Focal Vision System

Technical Field

This invention relates to machine vision systems, and more particularly to vision systems for reading bar codes.

Background Art

The parcel shipment industry is increasing the pace of automation in its package-handling and warehousing requirements to reduce delivery time and cost of handling. One such initiative includes the use of machine vision systems (optical readers) to automatically scan packages, without operator intervention, to read the package applied bar code which identifies the package routing, destination, and shipper/addressee. This application's challenge, however, is the necessarily high accuracy standard required to prevent misinformation in the shipping data despite the random depth of field requirements and random placement of the bar code within the camera's field-of-view due to variation in package size and placement on a conveyor belt.

In a typical application, the camera must focus on packages ranging in height from 0 - 92 cm with an image resolution suitable to read a 10 mil (0.010 inch; approximately 0.25 mm) character font

FIG.3

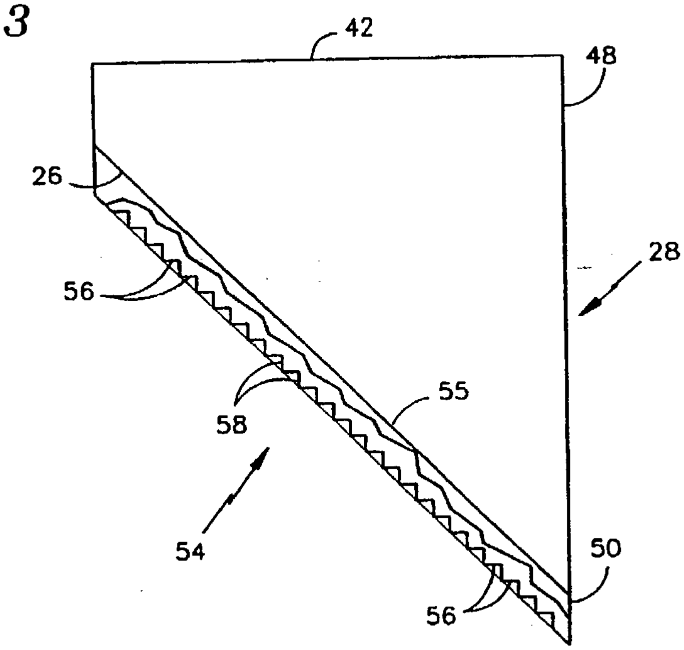
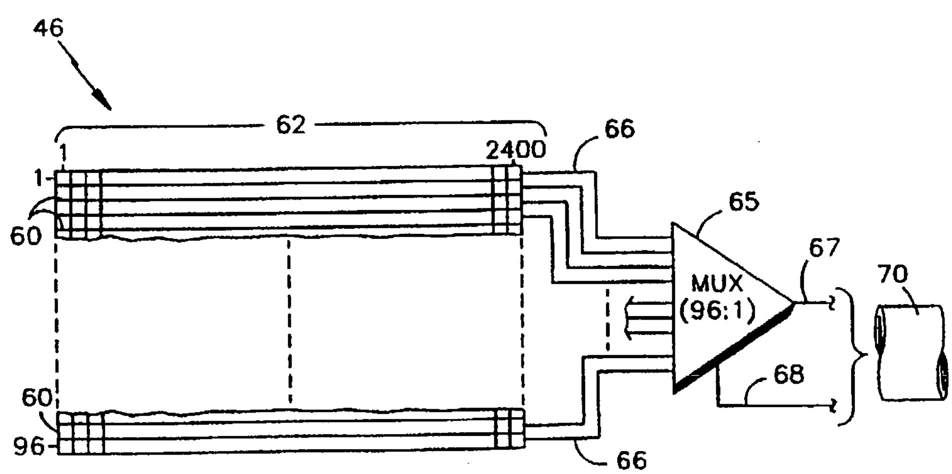

42
48
26
28
56
55
58
54
50
56

FIG.4


46
62
1
2400
66
1
60
65
MUX
(96:1)
67
70
68
60
96
66

photodetector which transduces the focused optical image into a corresponding electrical signal for further processing.

These and other objects, features, and advantages of the present invention will become more apparent in light of the following detailed description of a best mode embodiment thereof, as illustrated in the accompanying Drawing.

Brief Description of Drawing

Fig. 1 is a schematic illustration of a best mode embodiment of the camera system of the present invention for use in reading parcel bar codes;

Fig. 2 is an exploded, perspective view, not to scale, of the elements included in one component of the system of Fig.1;

Fig. 3 is a side elevation, partially broken away, of one of the elements illustrated in Fig. 2; and

Fig.4 is a schematic diagram of another element illustrated in Fig. 2.

Best Mode for Carrying out the Invention

Fig. 1 is a schematic diagram of a best mode embodiment of the present invention's multi-focal vision system 6. The system 6 includes: a system signal processor 7, such as a DOS based PC with an INTEL® PENTIUM® microprocessor having a standard full keyset keyboard 8 and SVGA 256 color video monitor 9; and a static focus camera 10. In the illustrated embodiment the system 6 is used to read optical bar codes placed on exposed surfaces 11 of random height

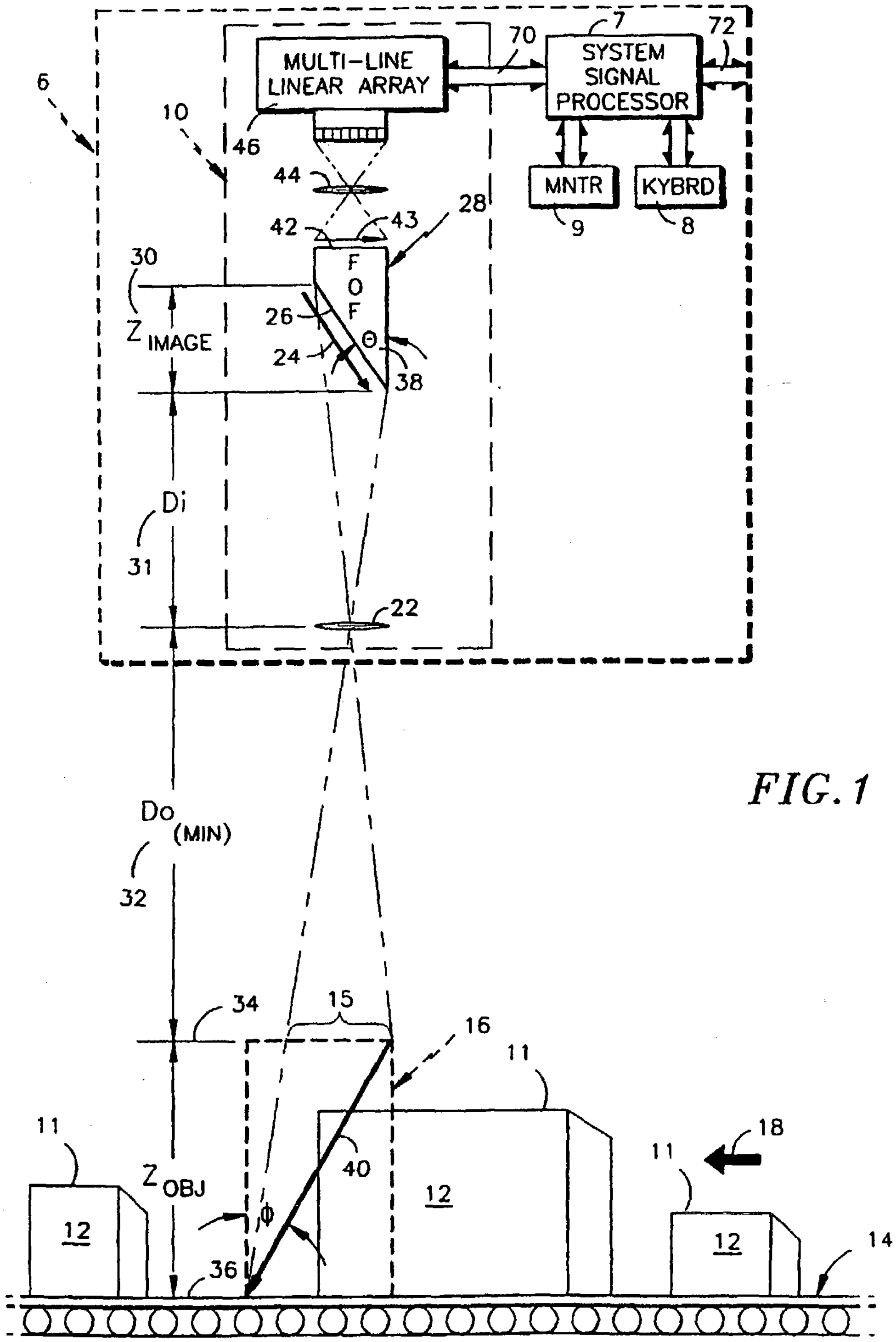

MULTI-LINE
LINEAR ARRAY
SYSTEM
SIGNAL
PROCESSOR
MNTR
KYBRD
7
72
70
6
10
46
44
42
43
28
9
8
30
F
O
F
26
Z IMAGE
24
Θ
38
Di
31
22
Do (MIN)
32
34
15
16
11
18
40
12
Z OBJ
Φ
36
14

FIG. 1

surface 36 of the belt 14 (e.g. envelopes).

This depth sensitivity is taken into account in the optical design of the imaging lens by selecting lens parameter values which minimize the image distance sensitivity to changes in object distance. We begin with the standard (lens maker's) imaging equation:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F} \qquad \text{(Eq. 1)}$$

where: D_o is the object distance, D_i is the image distance, and F is the focal length. Solving Eq. 1 for D_i and taking the partial differential $\delta(D_i)/\delta D_o$, produces the result:

$$\frac{\delta(D_i)}{\delta D_o} = \frac{F}{(D_o - F)} - \frac{(D_o \cdot F)}{(D_o - F)^2} \qquad \text{(Eq. 2)}$$

From this, values of D_o and F are selected such that $\delta(D_i)/\delta D_o$ is small while satisfying the application's requirements for the working object depth of field Z_{obj} and the image depth of field Z_{image}. By way of example, $\delta(D_i)/\delta D_o$ is small for combinations of F equal to or less than 200 mm, and D_o greater than 2000 mm. If we assume an application having a required $Z_{obj} \approx 900$ mm, a desired demagnification of 14 - 18, a minimum read resolution (minimum character width) of 0.010 inches, and an *f*/4 aperture, we see from Table 1 that a lens with a clear aperture (CA) diameter of 50 mm

Table 1

(Z_{obj})	$D_{o\,min}/D_{o\,max}$	$D_{i\,max}/D_{i\,min}$	Magnification	CA/F.	Image Resolution
900 mm	3000/3900 mm	214/210 mm	0.071 / 0.054	50/200	0.004 / 0.005 in.

FOF, said imaging lens means providing said focused optical image at said different object lengths from said plurality of different distance object focal planes to said receiving surface at an image depth of field Z_{image} which is substantially constant relative to said object depth of field Z_{obj}.

7. The system of claim 6, wherein:

said imaging lens means provides said focused optical image to said receiving surface at a demagnification gain.

8. The system of claim 3, wherein said camera means further comprises:

relay lens means, positioned intermediate to said output end of said FOF and said detector means, for relaying the focused optical image appearing at said output end from said optical fibers to said plurality of detector lines.

9. The system of claim 8, wherein said relay lens comprises an anamorphic lens to optically translate a set of spatial coordinates of said focused optical image from said output end to a set of array coordinates of said plurality of detector lines.

10. The system of claim 5, wherein said detector means further comprises:

switching means, responsive to a signal input thereof to each of said plurality of detector lines, and responsive to an address input

the tilted image space 24 at the receiving surface 26 is transformed to an untilted image 43 at the output surface. The line images are then re-imaged through relay lens 44 onto a multilinear detector array 46, in which each line of the array is mapped into a distinct height region in belt space.

Referring now to Fig. 2, which is an unscaled, exploded view of the axially aligned elements of the camera 10. These include, from input to output, the imaging lens 22, the FOF 28, the relay lens 44, and a partial cutaway of the multilinear detector array 46. For purposes of teaching only, Fig. 2 also shows, in figurative fashion, the system's pattern of line images 47. Each line images has a length (l), which extends transverse to the direction of belt travel, and a minimum width (W), which extends in the direction of belt travel and which is small enough to satisfy the minimum read resolution, e.g. 10 mils (0.010 inch) character font at the required object distance. The locus of the line image object lengths 48 form the trajectory of the primary image plane (40, Fig.1). The field of view of adjacent line images overlap to an extent such as to ensure that the sum of the line images provide a composite image of the vertical space through the Z_{obj} working depth of field.

The total number of line images (N_{lines}) required in a given application is a function of the working depth of field Z_{obj} (20, Fig. 1) and the required depth of focus (DOF_{line}) of the photodetector array 46. The value of DOF_{line} is defined by the application's working object distance D_o (where $D_o \equiv D_{o\,max}$), the clear aperture (CA)

registration with said plurality of detector lines; and

ii) an optical grating structure mounted coaxially to said receiving surface and comprising a plurality of optically transparent plateau surfaces disposed along a stepped trajectory which is substantially parallel to said receiving surface, each of said plurality of optically transparent plateau surfaces being associated with one of said line images and with a different object length region of said receiving surface to thereby provide an optical signal interface between a related one of said plurality of different distance object focal planes and said corresponding object length region of said receiving surface.

3. The system of claim 2, wherein:

said plurality of optically transparent plateau surfaces provide an image registration of said line images with receiving surface to form a composite FOV image, said image coherent waveguide substantially maintaining said image registration of said composite FOV image provided at said output end to said detector means; and

said plurality of detector lines each receiving the focused optical image of an associated one of said plurality of different distant

of their end face by the angle θ from the optical axis 52 (shown in phantom) of the camera 10, and produce the (90- ϕ)° degree displaced primary image plane 40. The value of the bias angle θ is a function of the required image depth of field Z_{image} and the line length (L) of the multilinear array 46, and is equal to:

$$\theta = \tan^{-1}(Z_{image}/L) \qquad \text{Eq. 5}$$

The angle is relatively steep; ranging from about 0.1 to about 0.5 radians (approximately 5 to 30 degrees), depending on the specific application. If the line images were received directly at this steeply tilted, polished surface, up to 40% of the received light would be lost due to Fresnel reflection. This would make the FOF 28 very polarization sensitive. Therefore, a critical and novel feature of the FOF design is the transparent interface structure 50.

Referring again to Fig. 2, the structure 50 includes a tilted sensor end 54 at a first major surface thereof, and a distal, second major surface 55 (this is the structure's back surface in Fig. 2 which is not visible in the illustration). The plane of the sensor end 54 and that of the back surface 55 are similarly displaced by an equivalent angle value θ from the camera optical axis 52 and, therefore, substantially parallel to the FOF input surface 26.

The sensor end 54 comprises a plurality of substantially equal dimension, stepped plateaus 56. The plateaus 56, which are more clearly shown in the partial cut-away, side elevation view of the housing in Fig. 4, are spaced apart at step intervals 58. The plateaus divide the image space 24 (Fig. 1) of the FOF input surface 26 into the number of line images (N_{lines}) required to gradate the Z_{obj} vertical

Claims

1. A machine vision system, for obtaining a focused optical image of an object appearing within a variable distance horizontal plane of an object field of the system comprising:

a) a camera means, having an optical axis, said camera means for providing a simultaneous plurality of line images, each one of said simultaneous plurality of line images having a field of view (FOV) of a transverse segment of the variable distance horizontal plane and each of said FOVs having a different object length, to provide a system object depth of field (Z_{obj}) having a composite FOV of the variable distance horizontal plane and having a vertical extent that is segment gradated over a range of said different object lengths into a plurality of different distance object focal planes, each said plurality of different distance object focal planes providing an optical image of objects appearing therein, said camera means comprising;

i) a detector means, having a plurality of photodetector elements linearly arrayed in a plurality of detector lines, for receiving said optical image from said plurality of different distance object focal planes, each of said plurality of detector lines transducing said optical image from an associated one of said plurality of different distance object focal planes

of the structure as illustrated in Fig. 2) to the input surface 26 of the waveguide. The bonding agent is preferably optical epoxy, but any other known bonding agents may be used as deemed suitable by those skilled in the art to meet the performance standards for the particular camera.

The relay lens 44 is an optional element of the camera 10, and is used primarily to gain flexibility in the relative placement of the FOF 28 to the detector array 46. The lens may be eliminated with close proximal placement of the FOF output 42 in register with the detector's array lines 60. Alternatively, the lens 44 may be used to provide an anamorphic image of the FOF output 42 to the detector, as required to fit the X and Y coordinates of the image to the array lines.

The lens 44 projects each of the received line images from the primary image plane (40, Fig.1) onto an associated one of the lines 60 within the detector's multi linear array 62. The number of lines 60 corresponds to the N_{lines} number of line images, and in turn to the number of plateaus 56. The relative positioning of the FOF output 42 and detector array 62 is such that each plateau is nominally in register with an associated one of the detector lines 60. Therefore, the array 62 receives a line-by-line composite image of the entire Z_{obj} vertical space, in which each of the lines (referred to also as detector rows) 60 is associated with a quantified segment of Z_{obj}. A focused bar code image will then appear in the line (row) whose Z_{obj} vertical segment coincides with the height of the parcel surface on which the bar code appears. Each line transduces its received line image into an electrical data signal representative of the optical image appearing

for processing bar code data in applications of this type.

The MUX 65 controls which pixels, from which array line are output from the camera 10 within each frame. Each addressed line of pixels must be read out serially, and the number of pixels required by each array 60 is equal to:

$$\frac{\text{(belt width x demagnification)}}{\text{pixel diameter}}$$

As newly available technologies, such as those used in charge Injection Devices (CID) and MOSFET switched arrays, mature they may be preferred over the modified TDI array since they will allow the desired array lines to be addressed in a direct X, Y fashion, even in segments, rather than the parallel-serial readout disclosed in Fig. 4. Nevertheless, the basic principals of accessing only those portions of the array which contain in focus information from the scanned field is the same.

In the present vision system, the selection of the correct readout line in the camera array is the result equivalent of the prior art systems which drive an active optical element to the correct focal position. In the present camera, however, the action occurs more quickly, and without mechanical motion, thereby improving efficiency and reliability while providing a sensed accuracy that is at least equal to, if not better than the prior art dynamic focus systems.

Similarly, the prior art dynamic focus cameras fail to perform in a situation where, due to the random nature of parcel placement, multiple, different height parcels passing simultaneously (side-by-side) rather than sequentially through the object field. The mechanical

height. The dimensioning system may be any one of a number of known optical systems which measure the dimensions of the parcels 12, including the height of the parcel surface 11 above the belt surface 36. The sensed height magnitude is converted to a signal magnitude whose full scale is correlated to Z_{obj}. Similarly, the array lines 60 are correlated to Z_{obj} by their quantified segment, such that each line 60 has a corresponding signal magnitude on the full scale of the dimensioning system. In this manner each height signal magnitude may be correlated with a specific array line containing the focused bar code image.

Therefore, in the present vision system, the array 62 gradates the working depth of field Z_{obj} into vertical segments, each of which are correlated with a corresponding line of the array and to an associated value of a height signal magnitude received from an upstream dimensioning system, such that only the one line of the array which is at the correct focus is read out to develop the image necessary for the bar code reading. The out-of-focus image data in all of the remaining lines are discarded.

Fig. 4 is a schematic block diagram of the detector 46, with lines 60 positioned lengthwise in the array 62 so as to be substantially in register with the length dimension (l) of the line images (47, Fig. 2); transverse to the parcel direction of travel (64, Fig. 2). In the best mode embodiment the array 62 is a modified Time Delay and Integrate (TDI) array. As known, TDI arrays are charge coupled device (CCD) detectors in which the charge data is read out serially, one line at a time. In operation, a standard TDI array laterally shifts